Very Slack Strings: A Physical Model and Its Use in the Composition "Quartet For Strings"

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ABSTRACT

Virtual "slack" strings are designed for and employed by the Laptop Orchestra of Louisiana. These virtual strings are "slack" in the sense that they can be very easily displaced, bent, tugged upon, etc. This enables force-feedback control of widely ranging pitch glides, by as much as an octave or more, simply by bending the virtual string. To realize a slack string design, a virtual spring with a specific nonlinear characteristic curve is designed. Violin, viola, and cello-scale models are tuned and employed by the Laptop Orchestra of Louisiana in *Quartet for Strings*.

Author Keywords

Nonlinear string, physical modeling, haptic force feedback

ACM Classification

H.5.5 [Information Interfaces and Presentation] Sound and Music Computing, H.5.2 [Information Interfaces and Presentation] User Interfaces—Haptic I/O.

1. INTRODUCTION

Physical modeling is a powerful technique for synthesizing both sound and haptic force feedback [8, 4]. The authors create a virtual string that supports multiple modes of interaction via a haptic force-feedback interface (see Figure 1) [2]. In other words, it is not only possible to **pluck the string and feel the vibrations via a virtual plectrum**, but it is also possible to **adjust the pitch of the string while simultaneously feeling its vibrations**. The latter is related in metaphor to the way that the berimbau instrument's pitch can be increased by pressing on the string with a stone or coin [5].

Figure 1: The FireFader open-source hardware haptic force-feedback device.

2. MODEL DESIGN

Using the mass-link paradigm first applied to music by Cadoz et al., a virtual string can be simulated by interleaving virtual `masses` (●) and springs (e.g. linear `links`) [4]. In the present work, the model is implemented in Synth-A-Modeler [3], meaning that the International System of Units is employed, and the model can be compiled into a wide variety of targets via the Faust compiler [6].

However, the pitch of a string made with purely linear `links` will not increase continuously when touched by a performer. It is necessary to use more complex models of springs, whose stiffness increase as they are stretched. In other words, the links must be `stiffeninglinks` ( ). They cause the string to then exhibit the phenomenon of tension modulation [5], which occurs due to the following. When the string is plucked, it vibrates and on average the `stiffeninglinks` are stretched further than when at rest. This causes their stiffness to increase on average, so consequently the pitch increases as well. As the energy in the string decays and its vibrations become smaller, the "average stiffness" decreases accordingly, allowing the pitch to gradually decrease back to its resting pitch.

The following equation can be used to describe the desired force characteristic of the `stiffeninglinks`:

$$F_{stiffeninglink}(x) = kx + \frac{1}{\beta^2} \cdot \frac{k_S x^3}{1 + \frac{x^2}{\beta^2}} + R\dot{x}, \qquad (1)$$

where R is the damping parameter in $N/(m/s)$, k is the stiffness in N/m when the string is at or near rest (e.g. $|x| \ll \beta$), and $(k+k_S)$ is the maximum stiffness in N/m that is achieved when $|x| \gg \beta$. To not only facilitate comfortable control of the string pitch but to also endow a warm and bright tension-modulated timbre, $\beta = 0.001$ m is selected. This means that unless the string vibrations are considerably smaller than 1 mm, the string will sound warmer and be pitch modulated due to the nonlinear characteristic (1).

The model now needs to be modified slightly so that the performer can, using a second hand, increase the average displacement (and therefore "average stiffness") of each of the `stiffeninglinks` by manually applying pressure. This is achieved by connecting a `touch` link (, sometimes alternatively referred to as a "contact link") in between the second `port` (see the at the top of Figure 2) and each of the `masses`.

3. QUARTET FOR STRINGS

Quartet For Strings is a music composition written by the co-author Stephen David Beck.[1] Each performer plays a scaled version of the model via a FireFader haptic device. The nonlinear stiffening spring aspects of the models are exaggerated in order to explore the questions:

> How would the slack strings be best controlled? Could these virtual "extraordinarily slack strings" be used to create a musical quartet akin to a real-world string quartet, where pressure is applied to change the string pitch instead of changing the

[1] `https://cct.lsu.edu/~eberdahl/V/QfS.mov`

NIME'16, July 11-15, 2016, Griffith University, Brisbane, Australia.
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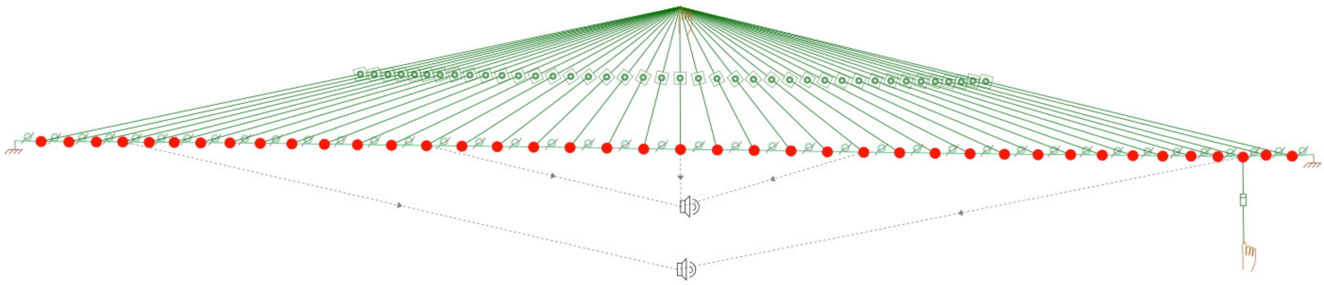

Figure 2: A performer can increase the pitch of the very slack string by applying pressure on all of the masses across the string via the port shown at the top.

string length? How could the work be notated and performed?

Although it might be possible to build such instruments in the real world, it is generally challenging to find materials that are playable and nonetheless slack/nonlinear/"gooey" enough to meet these requirements, without simultaneously also being very fragile. For this reason, playing virtualized versions of such strings using haptic force-feedback devices is an alternative.

Quartet for Strings was composed as a modular and sectional piece combining quasi-spatial notation with a three line staff representing relative pitch elements (see Figure 3). While precision of time and pitch is not critical to its performance, the piece was conceived as a composed, and not as an improvised work. It balances control over gesture and density with aleatoric arrangements of the parts. The Fourth Movement of Witold Lutosławsi's *Venetian Games* features a similar approach to texture [7].

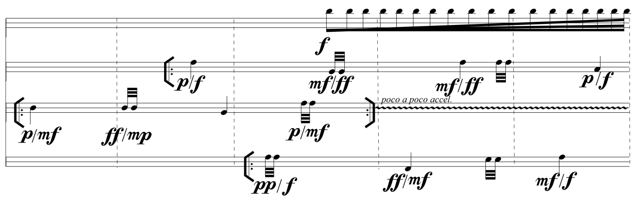

Figure 3: Excerpt from *Quartet for Strings*.

The stiffness k is tuned to realize treble, alto and bass registers. Each performer can apply pressure to the model by depressing the left of the faders on the FireFader (see Figure 1). This increases the string tension and raises the string's pitch. The farther the player depresses the string, the more resistance is felt because of the `stiffening links`. To pluck the string, a performer uses the right fader.

The composition leverages two special techniques that exploit the FireFader's force-feedback. First, a performer can fully depress the string and quickly release the tension on the string. The haptics force the left fader to quickly move back to a resting position. The sound of this technique is reminiscent of a Bartók pizzicato except that the pitch descends rapidly during the attack. This can be heard after the slow introduction in the lowest sounding instrument.

A second technique requires that the performer lightly depress the left fader to lightly make contact with the virtual string. The model responds accordingly with force feedback to push the fader in the opposite direction (against the performer's finger). When the pressure the performer exerts on the fader and the response the model creates are applied in a particular proportion, the fader exhibits a rapid oscillation. This technique is used extensively near the end of the piece. The sound that is produced by this technique is reminiscent of tremolo on a stringed instrument, except that in this case, the instrument is actively assisting the player in performing the gesture.

4. CONCLUSION

Throughout the model design process, it was attempted to adhere to the principles of acoustic viability [1]. In contrast with other sound synthesis techniques, physical models may tend to automatically result in the creation of acoustically viable sound synthesizers. However, during the modeling process, many decisions are made that greatly affect the sound of the models. Physical model designers can choose which physical aspects to incorporate and which physical aspects to neglect. In this work, nonlinear stiffening spring behavior was incorporated in order to provide more variety in the string timbre, to make the amplitude envelope more complex, and to allow the string sound to get brighter when plucked harder. These are higher-order effects that are observed in real strings, to greater or lesser extents.

Our effort shows that these models can be used for artistic pursuits, and the authors plan on future composition projects.

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